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Abstract

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The U.S. Department of Agriculture/U.S. Agency for International Development Project on Technology for Soil Moisture Management (TSMM) has been designed to provide technical assistance for the development of improved dryland and rainfed farming systems. This report describes TSMM's activities in agronomic and economic research, sponsorship of symposia and training, establishment of a network for sustainable agriculture, and publications.

KEYWORDS: Soil and water conservation, international development, crop and livestock management systems, dryland agriculture, rainfed agriculture, sustainable agriculture, farming systems.

While supplies last, single copies of this publication may be obtained, at no cost, on request from Dr. James F. Parr, Coordinator, USDA/USAID Dryland Agriculture Project, Rm 414, Bldg 005, BARC-West, Beltsville, MD 20705. (Telephone: (301) 504-5281; FAX (301) 504-6191)

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Technology for Soil Moisture Management

Progress Report
February 1988 to July 1991

Dryland areas of the world

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Glossary

APNAN	Asia-Pacific Natural Agriculture Network
ARS	Agricultural Research Service, U.S. Department of Agriculture
CAZRI	Central Arid Zone Research Institute, India
CRIDA	Central Research Institute for Dryland Agriculture, India
CSRS	Cooperative State Research Service, U.S. Department of Agriculture
EC	Economic Component
ERS	Economic Research Service, U.S. Department of Agriculture
FAO	Food and Agriculture Organization, United Nations
FERRO	Far Eastern Regional Research Office, India
IARC	International Agricultural Research Center of the Consultative Group for International Agricultural Research
IBSNAT	International Benchmark Sites Network for Agrotechnology Transfer
ICAR	Indian Council of Agricultural Research
ICARDA	International Center for Agricultural Research in the Dryland Areas
ICRISAT	International Crops Research Instltute for the Semi-Arid Tropics
IITA	International Institute for Tropical Agriculture
IPCC	Intergovernmental Panel on Climate Change
JUST	Jordan University of Science and Technology
MFAD	Manpower for Agricultural Development Project, Uganda
OICD	Office of International Cooperation and Development, U.S. Department of Agriculture
PASA	Participating Agency Service Agreement
RSWG	Response Strategies Working Group of IPCC
SACCAR	Southern African Centre for Cooperation in Agricultural Research
SADCC	Southern African Development Coordination Conference
SAFGRAD	Semi-Arid Food Grain Research and Development
SCS	Soil Conservation Service, U.S. Department of Agriculture
TROPSOILS	A Collaborative Research Support Program in Tropical Soils
TSMM	Technology for Soil Moisture Management
USAID	U.S. Agency for International Development
USDA	U.S. Department of Agriculture
WORLD BANK	International Bank for Reconstruction and Development
WSU	Washington State University

Contents

Overgrazing of native rangelands combined with normal dry conditions turned this site in the U.S. Southwest into nonproductive scrubland 50 years ago. ARS researchers found ways to restore productivity to these once degraded lands.

Foreword

ARS has the largest group of scientists and engineers in the world conducting research on soil-, water-, and crop-management systems for dryland agriculture.

Since 1983, a Participating Agency Service Agreement (PASA) has existed between the Agricultural Research Service (ARS) of the U.S. Department of Agriculture (USDA) and the Science and Technology Bureau of the U.S. Agency for International Development (USAID). In 1985, the USDA Economic Research Service (ERS) joined with ARS in the PASA. The overall objective of the USDA/USAID PASA Project for Dryland Agriculture—also known as Technology for Soil Moisture Management (TSMM)—is to provide assistance to USAID projects for improving soil- and water-management practices in dryland or rainfed agricultural systems in developing countries. The Project is administered through USDA's Office of International Cooperation and Development. TSMM's efforts are directed toward the extremely poor countries in three geographic regions that have a critical need to increase the productivity and stability of dryland farming systems. Those regions are the Near East, sub-Saharan Africa, and South-Southeast Asia.

The major physical constraints on increased agricultural productivity and sustainability in these regions are marginal soils (coarse-textured, sandy, low in fertility, low in organic matter, and low in water-holding capacity), erratic rainfall patterns, drought, and intensive tillage. The rate and extent of soil degradation (from erosion, nutrient runoff, organic matter depletion, and desertification) have increased because of poor management and inadequate soil- and water-conservation practices. Such conditions are similar to those that we faced in the drylands of the U.S. Great Plains and that led to excessive wind erosion and the infamous Dust Bowl of the 1930's. For more than 50 years following this disaster, ARS has conducted extensive research to develop productive, environmentally sound, and economically viable dryland farming systems that are sustainable over the long term.

ARS has the largest group of scientists and engineers in the world who are conducting research on soil-, water-, and crop-management systems for dryland agriculture. This program has become even more important in the United States in recent years because of the increased economic costs and technological problems associated with irrigated agriculture.

The USDA/USAID PASA Project has been a mutually beneficial and productive effort for ARS and ERS. Our scientists, engineers, and economists who have served as consultants to this Project have returned from their assignments with increased knowledge and ideas for highly relevant research on aspects of conservation tillage, soil and water conservation, soil fertility management, integrated pest management, crop rotations, and crop residue management. The Project has fostered the two-way flow of technical information on dryland farming between the United States and developing countries. We look forward to the continuation of this excellent cooperative program with USAID in the years ahead.

Dr. R. Dean Plowman
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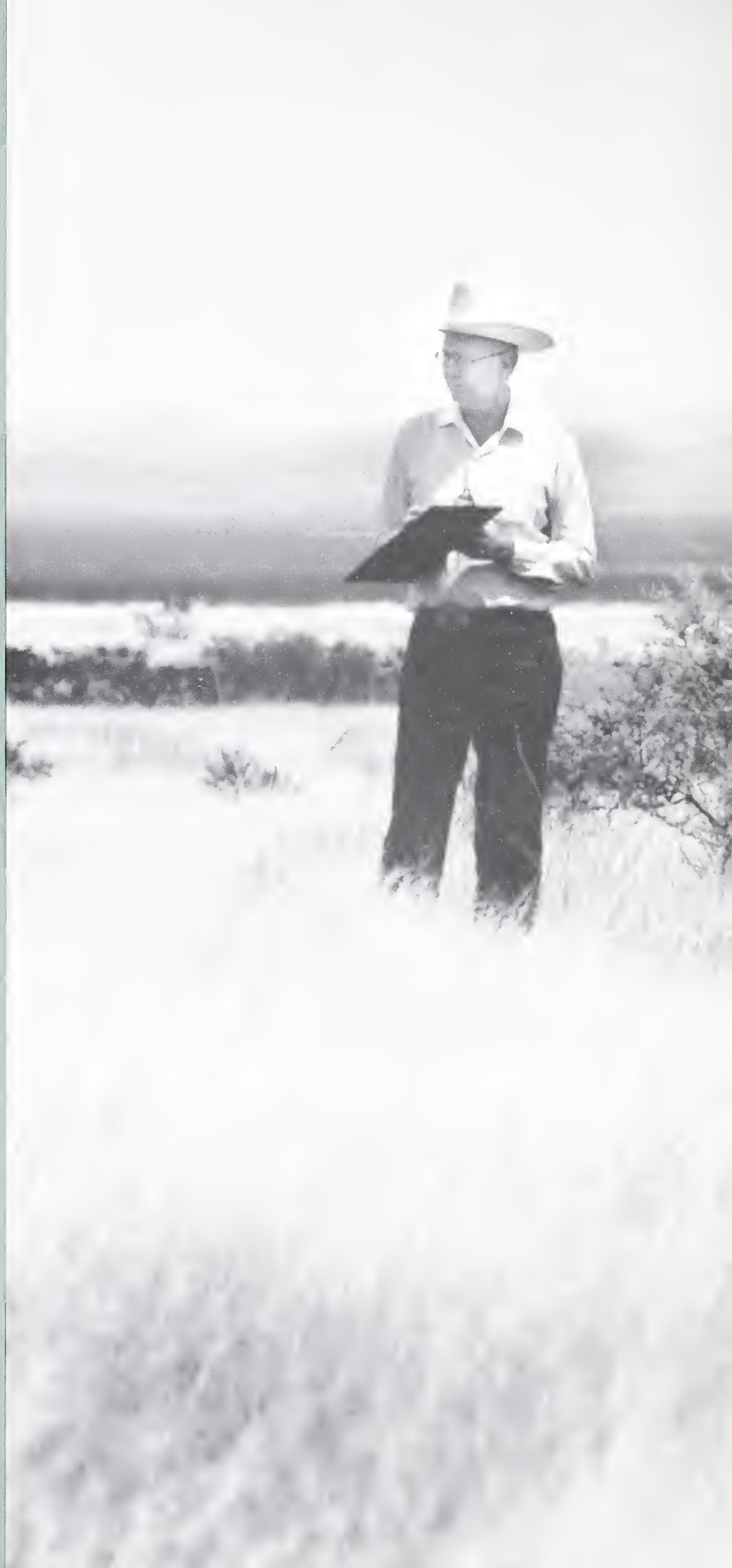
The integration of both agronomic and economic concerns to solve soil- and water-management problems makes this project unique.



Executive Summary

The project Technology for Soil Moisture Management (TSMM) has been designed to provide technical assistance for the development of improved dryland farming systems.

Low-rainfall areas constitute the major portion of the land area in many countries in the Near East, sub-Saharan Africa, and South Asia. These drylands traditionally produce most of the food grains and fibers consumed by their 700 million inhabitants. But in recent years, grain production per capita has declined. Currently the productivity in these areas is just a fraction of that obtained under comparable agroclimatic conditions in the United States. Productivity of developing, low-rainfall areas can be increased by the improved management of soil and water resources.

The U.S. Department of Agriculture/ U.S. Agency for International Development (USDA/USAID) Project on Technology for Soil Moisture Management (TSMM) has been designed to provide technical assistance for the development of improved dryland and rainfed farming systems. The purpose of the program is to assist developing countries in (1) the agronomic and economic assessment of their soil-, water-, and crop/livestock-management systems under dryland or rainfed conditions, and (2) the formulation of national strategies for increasing their agricultural productivity through research and technology transfer. TSMM helps these countries develop networks of research, extension, donor, and policy institutions for cooperative research and for the exchange of information on agricultural systems management.

TSMM also allows continual interchange between the U.S. scientific community and the scientific communities of the participating countries in the international agricultural research community. The Participating Agency Service Agreement among the Agricultural Research Service (ARS) and the Economic Research Service (ERS) of USDA and the Science and Technology Bureau of USAID makes use of the skills of ARS scientists, ERS economists, and land-grant universities, which have been studying problems specific to drylands and dryland agriculture in the U.S. Great Plains and the Pacific Northwest for more than 50 years.

In the past year, TSMM has helped scientists in Jordan develop a database on soil, water, and crop management for rainfed agriculture; provided assistance to four countries in the Near East for the development of a Ribbon Project on rainfed cereals and the relative value of crop residues for soil and water conservation versus feed for small ruminants; cooperated with USAID/Mali to conduct a case study on the economics of improved soil and water management; and provided technical assistance to several other countries, including Niger, Senegal, and Rwanda. TSMM has played a key role in the planning and development of five major research projects on dryland agriculture in India that were implemented in early 1990 under the PL-480 Program and administered by the Far Eastern Regional Research Office of USDA's Office of International Cooperation and Development in New Delhi.

TSMM was also a cosponsor and was instrumental in the planning and organizing of an International Conference on Dryland Farming held in Amarillo, Texas, on August 15-19, 1988. Through its annual study tour of dryland/rainfed farming systems in the U.S. Great Plains, TSMM has helped make project managers and staff of international development agencies aware of U.S. expertise in dryland technologies. TSMM has increased communication among scientists who are working on soil- and water-management problems. This has been effectively accomplished in most cases through the integration of both agronomic and economic concerns. In this regard, TSMM is unique.

TSMM's Ribbon Project develops strategies for resolving problems such as when to use crop residues for soil conservation or for livestock feed.

Project Rationale

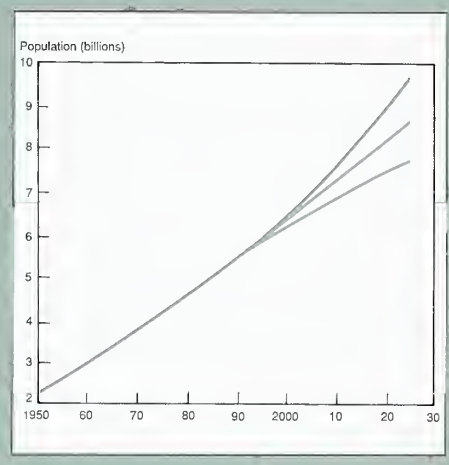
Problem Definition

Dryland agriculture is a rainfed crop production system in which a major limiting factor is water. In addition to erratic and limited rainfall, many dryland areas have severe problems of soil quality. These problems include low water-holding capacity, hardening of surface soil, compaction, low water-infiltration rates and consequent excessive water runoff and soil erosion, erosion from wind, coarse texture, shallow depth, restricted drainage, salinization, and low fertility. Consequently, dryland farming is a risky enterprise.

In the past, irrigation projects in arid and semiarid regions have reduced the risk associated with a variable water supply and have helped farmers increase food production. But as the cost of irrigation and drainage projects has risen, the rate of development of the projects has slowed. Yet the demand for food and fiber will continue to increase as the population in developing countries expands by some 3 billion persons over the next 35 years.

Currently, 80 percent of all cultivated land is dryland or rainfed. It seems axiomatic, then, that long-term improvement in world food production will depend on enhanced, sustainable productivity in drylands.

The demand for food and fiber will continue to increase as the population in developing countries expands by some 3 billion persons over the next 35 years.



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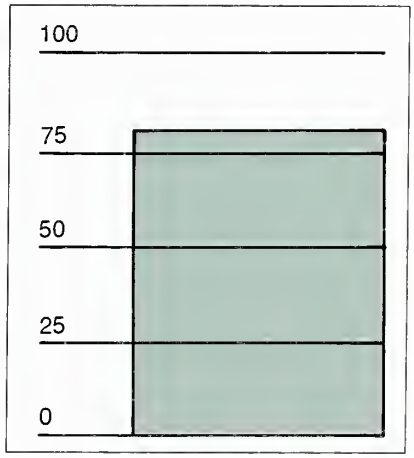
One of the best examples of improving the productive capacity of dryland is the Great Plains area of the United States. Following a decline in the early 1900's, dryland productivity has increased steadily since the late 1930's as a result of governmental policies and agricultural research. Today, wheat yields in the U.S. Great Plains are two to four times those of the Near East and North Africa.

Improving the productivity of drylands is essential to raise the living standards of their 700 million inhabitants and to prevent the escalating calamities seen with recent droughts. A decrease in land degradation and an increase in the productivity of low-rainfall areas can be achieved by improved management of soil and water resources. In many locations, improvements can be achieved by the more widespread application of known principles of soil and water management to crop and livestock production. Other situations require new concepts and methodologies that are

In the 1930's, farms such as this in Guymon, Oklahoma, became part of the Great Plains' Dust Bowl. Intensive cultivation, overgrazing, and drought contributed to severe wind erosion and the region's devastation. (Courtesy of USDA, Soil Conservation Service.)



Eighty percent of all cultivated land is either dryland or rainfed.

appropriate to the unique aspects of developing areas.

Governmental policies, land-tenure arrangements, and social, cultural, and economic factors also influence the way in which dryland resources are used. Achieving long-term sustained growth in the productive capacity of low-rainfall areas will require sound decisions based on accurate assessments of resource problems and potentials and on careful analysis of alternative policies, programs, and projects.

Objectives

Technology for Soil Moisture Management (TSMM), also known as the U.S. Department of Agriculture/U.S. Agency for International Development (USDA/USAID) Dryland Agriculture Project, is a Participating Agency Service Agreement (PASA) between USAID and USDA. Under the contract, USDA's Agricultural Research Service (ARS) provides technical expertise to USAID projects for improving agricultural management in dryland and rainfed systems.

The overall goals of TSMM are to increase the productivity and long-term sustainability of rainfed/dryland agricultural systems in developing countries while maintaining or enhancing the natural resource base (specifically the soil and water resources) and to improve output and income in crop- and livestock-production systems. To achieve this, TSMM combines agronomic and economic components with the following objectives:

(1) To assist in the assessment of soil-, water-, and crop/livestock-management systems under dryland or rainfed conditions;

(2) To develop effective strategies and approaches for increasing dryland and rainfed agricultural productivity through research and technology transfer;

(3) To generate information improving the knowledge and understanding of socioeconomic relationships that influence the way land and water resources are managed in rainfed/dryland agricultural production systems;

(4) To assist developing countries in applying better knowledge and expertise in evaluating the economic costs and benefits of policies, programs, and projects affecting agriculture; and

(5) To strengthen the capability of developing-country scientists and institutions for conducting research that will lead to more effective and efficient management systems for dryland and rainfed agriculture.

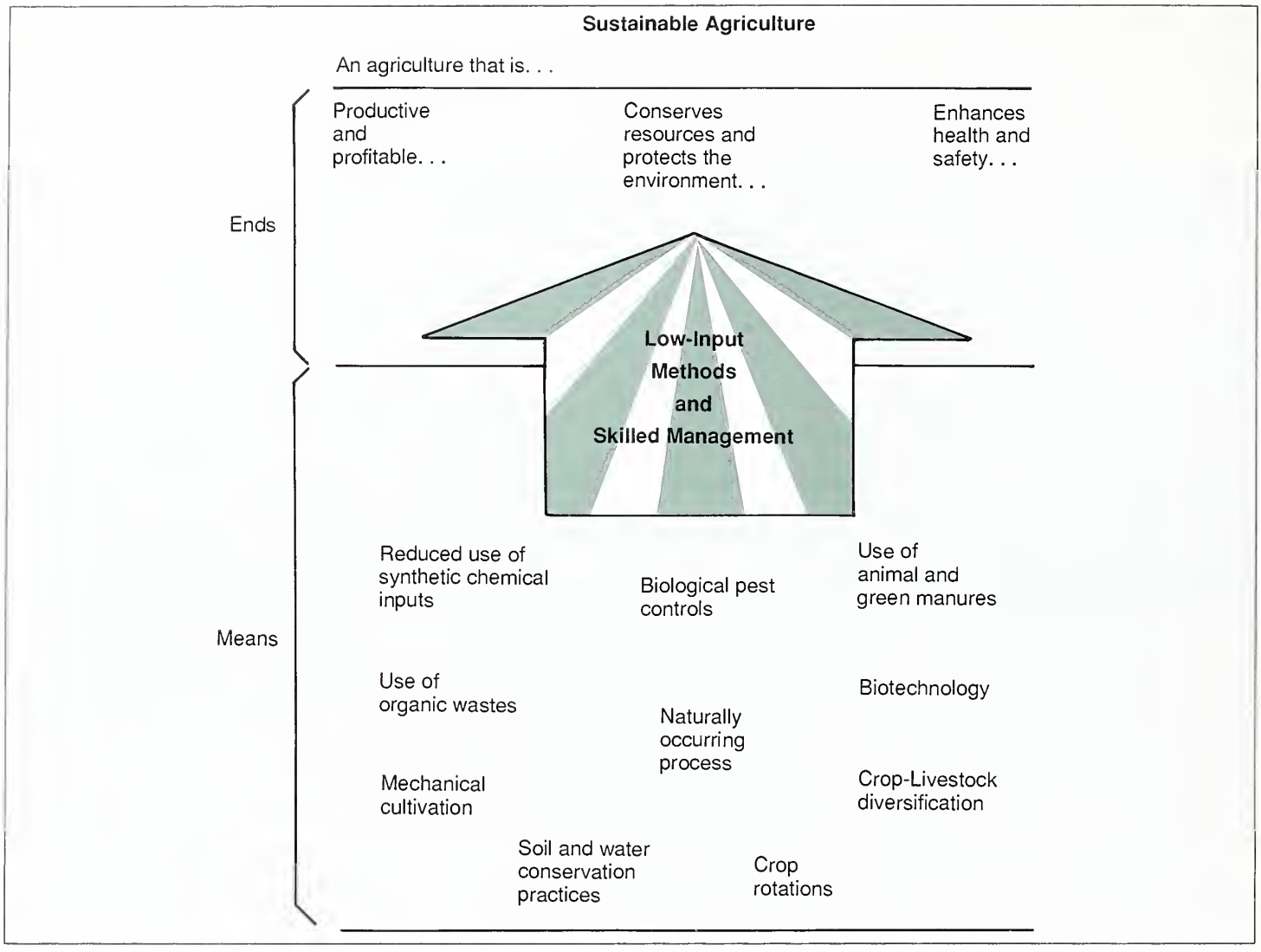
The major geographic regions of emphasis are the semiarid regions of the Near East, sub-Saharan Africa, and South Asia.

With this PASA, USAID has enlisted the best technical expertise in dryland agriculture developed over the last 50 years in the U.S. Great Plains and the Pacific Northwest. In the last 6 years, TSMM has helped scientists develop databases on soil, water, and crop management for dryland/rainfed agriculture; sponsored workshops; assisted in development of a Ribbon Project; provided technical assistance to several countries; and helped to improve communication among researchers working on the agronomic and economic problems of soil and water management in dryland/rainfed systems.

Approach

Currently, TSMM is active in several countries in each region. One approach involves linking the scientific communities in countries that have common research goals and objectives. This should lead to a better under-

Wheat yields in the U.S. Great Plains have steadily increased since the late 1930's as a result of governmental policies and agricultural research.



Current concept of sustainable agriculture showing the objectives and the means of achieving them.

standing of dryland resources, the production potentials of those resources, and the economic system of which the resources are a part. Steps in this linking would include development of the following:

(1) A database of existing research information on the soil and water resources and the production systems;

(2) Workshops with participants from the host country, international research organizations, developed-country scientists, and developing-country scientists to outline priorities for research activities; and

(3) Research activities linked by common research objectives and methodology and conducted in both developing and developed countries to bring about improved understanding and extrapolation of results to the areas of need.

It is hoped that this stepwise method of assessing knowledge, identifying problems, and mobilizing available resources for the development of solutions will serve as a model approach for other countries within each region.

TSMM engages in the following specific activities to accomplish its goals and objectives:

(1) Establishment and maintenance of an information network and scientist-to-scientist linkages among soil- and water-management specialists in the U.S. land-grant universities, USDA's ARS and Economic Research Service (ERS), developing-country institutions, international organizations, and USAID missions. This network and linkage should stimulate regional collaboration, cooperative research, and technology transfer for improved soil- and water-management systems.

(2) Provision of scientists and economists from soil- and water-resource management for short-term technical assistance and consultations on special problems and on proposed and ongoing research projects.

(3) Development of automated data and information systems that integrate agronomic, agroclimatic, and economic variables for the comprehensive assessment of resource-management options by both researchers and resource managers.

(4) Conducting case studies and other analyses of practices of alternative agricultural production for their potential socioeconomic impact at the farm, community, regional, and national levels.

Accomplishments

To achieve its objectives, TSMM has successfully collaborated with other agencies, research centers, and universities (see app. A). Many reports and publications have resulted from these collaborations (see app. B) .

U.S.-India PL-480 Dryland Project

In early 1987, the Indian Council of Agricultural Research (ICAR) requested that a U.S. Dryland Farming Team visit dryland research centers and institutes in India in order to assess ongoing and planned research activities and to recommend and prioritize future research needs toward improving the productivity and sustainability of dryland/rainfed agriculture in India. This request was expedited through the Far Eastern Regional Research Office (FERRO) of USDA's Office of International Cooperation and Development (OICD) in New Delhi.

FERRO is responsible for developing cooperative research projects under the PL-480 program that are of mutual interest and of potential benefit to both Indian and U.S. agriculture. Accordingly, a U.S. Dryland Farming Team headed by J.F. Parr, Coordinator, USDA/USAID Dryland Agriculture Project, visited India in March and April 1987, followed by the visit of a U.S. Economics Team in June 1987. The Combined Report of these two teams and their recommendations for strengthening Indian research on dryland agriculture were published in December 1987 under the auspices of the Indo-U.S. Subcommission on Agriculture.

Since publication of the Combined Report, Dr. Parr and other members of the U.S. Dryland Farming Team have provided counsel and technical input to ICAR and FERRO in their efforts to develop PL-480 research projects in accordance with the recommendations and priorities cited in the Report. Subsequently, five research projects emerged as the consensus recommendations by ICAR, FERRO, and the U.S. Dryland Farming Team for possible funding by the U.S.-India Rupee Fund. Funding of these PL-480 projects was approved in July 1989 for a total of Rs45 million (approximately US$3 million) over a 5-year period.

Dr. Parr has been named U.S. Coordinator for all five projects. A description of each of these multilocation, multidisciplinary projects follows.

Development of Models to Simulate Field-Moisture Balance, Water Uptake by Crops, and Water Use-Yield Relations in Arid and Semiarid Regions of India

R.I. Papendick and K.E. Saxton, USDA/ARS, Pullman, Washington, are the U.S. cooperating scientists for this project. They will be working with Indian researchers at the Punjab Agricultural University in Ludhiana to model field water use and crop yields for the maize/wheat-farming system in northern India. Simulations of field-moisture balance and water use-yield relations in the Indian arid zone will be developed and tested by scientists at the Central Arid Zone Research Institute (CAZRI) in Jodhpur. Scientists at the Central Research Institute for Dryland Agriculture (CRIDA) in Hyderabad will calibrate and modify the crop-simulation model CERES SORGHUM for use in the Indian drylands.

Enhancing Efficiency of Fertilizer Use in Conjunction With Residue Management in Dryland Crops and Cropping Systems

J.L. Havlin, Department of Agronomy, Kansas State University, is cooperating with scientists at CAZRI, CRIDA, and Punjab Agricultural University. Experiments have been designed to evaluate soil-water- and nitrogen-management practices for increasing the efficiency of water and nitrogen use.

Germplasm Enhancement for Drought Tolerance and Reclamation of Wastelands

Genetic and physiological studies will be undertaken by scientists at CRIDA, CAZRI, Solapur, and Bijapur in cooperation with J.D. Eastin, Department of Agronomy, University of Nebraska at Lincoln. This research will focus on increasing the water-use efficiency and nitrogen-use efficiency of specific crops, in addition to determining the physiological basis of stable yield under drought.

Integrated Project for Soil Conservation and Watershed Management

D.K. McCool and K.E. Saxton, USDA/ARS, Pullman, Washington, are cooperating with agricultural engineers at Bellary, Agra, Bangalore, and Indore. These studies are designed to determine the relative advantages and disadvantages of vegetative and mechanical bunds for erosion control under Indian conditions, improve our understanding of water erosion through the testing of extant erosion models, and develop water-harvesting schemes for onfarm use.

Mechanization of Dryland Agriculture

J.E. Morrison, USDA/ARS, Temple, Texas, and K.E. Saxton, USDA/ARS, are cooperating with Indian engineers at six sites. They will be working to develop small-scale mechanized implements for use with manual and animal draft for tilling, cultivating, harvesting, and threshing operations. They will also be improving equipment for the precision placement of seed and fertilizer.

Economic Studies

TSMM's Economic Component (TSMM/EC) is carried out by USDA/ERS under the direction of J.C. Day. In order to increase resources available to TSMM, ERS has entered into Cooperative Research Agreements with two State land-grant universities: Purdue University (West Lafayette, Indiana) and Washington State University (WSU) (Pullman, Washington). Principal investigators are R.R. Deuson at Purdue and W.R. Butcher at WSU.

TSMM/EC has undertaken a number of activities to support its objectives. The principal outputs of TSMM/EC fall into three categories:

(1) Development of various analytical tools and models that are appropriate for evaluating soil, water, and related farm-production practices in dryland farming systems;

(2) Case studies and other analyses of alternative agricultural production practices to estimate potential changes in farm production, resource use (including erosion and food consumption) and income in typical farming systems; and

(3) Automation of the multidisciplinary input data used in items 1 and 2 and preparation of necessary database documentation to improve general use by researchers and resource managers. Specific outputs within these categories relate to data systems, modeling, and case studies and are summarized below.

Automated Data and Information Systems

In order to analyze and provide more systematic evaluation of farm economics, it is necessary to have information on soils, weather, agronomic practices, crop-yield responses, and farm characteristics. In the semiarid and arid zones of the developing world, agroclimatic and agronomic data are often in short supply and/or are incomplete. Thus, it has been necessary to collect, organize, and automate data from a number of sources.

Development of Database. To date, TSMM/EC's database consists primarily of technical information on the soils, weather, agronomic practices, and farm characteristics in the rainfed areas of Niger, Mali, Cameroon, Benin, Syria, and Jordan. Consistently organized and accessible by personal computers, such a database is useful for bringing together data from a number of sources not only for our own immediate research studies but also for work directly in support of USAID missions in the field.

TSMM/EC's budget has never supported the collection of primary data, so TSMM/EC relies on secondary data sources and primary data already collected by or to be collected by collaborating institutions. In the case of the latter source, efforts by TSMM/EC to categorize, organize, and automate raw data files has been of benefit to its collaborators. TSMM data include the following:

- Niger Experimental and Farm Trials, in collaboration with the National Institute for Agricultural Research in Niger;
- North Jordan Farm Surveys, in collaboration with the International Center for Research in the Dry Areas (ICARDA);
- Northern Jordan Field Trials, in collaboration with the Jordan University of Science and Technology (JUST) and ICARDA;
- North Cameroon Farm Trials and Farm Surveys, in collaboration with the Semi-Arid Food Grain Research and Development Program (SAFGRAD) in Cameroon;
- North Benin Farm Survey, in collaboration with SAFGRAD in Benin;
- Burkina Faso Farming Systems Database, with source institutions being the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), International Institute for Tropical Agriculture (IITA), World Bank, Purdue University, USDA, University of Hawaii (International Benchmark Sites Network for Agrotechnology Transfer, IBSNAT), and WSU; and
- Niger Phosphate Trials Database, in collaboration with the International Fertilizer Development Center and the ICRISAT Sahelian Center, Niamey.

Crop Growth Model and Soil-Water Balance Model. Information on crop yield responses to various tillage practices, multiple cropping, and inputs such as water and fertilizer is also required for the economic analyses of new farm-production technologies. Crop growth models and soil-water balance models, properly calibrated to fit local conditions, can be particularly useful where data are unavailable.

In the semiarid and arid zones of the developing world, agroclimatic and agronomic data are often in short supply and/or incomplete.

However, complex models that have large requirements for data and computer capacity are of limited practical use. Therefore, TSMM/EC has developed simple, minimal data set approaches that can generate accurate information in a reasonable length of time. These have been integrated with economic farm models to form the basis of a series of case studies on soil-, water-, and crop-management issues in Africa and the Near East.

The following models have been developed or adapted for use by TSMM/EC:

- Soil-Water Balance/Crop Yield Response Model;
- Millet-Cowpea Crop Growth Model;
- Linear Response and Plateau Model for crop response to fertilizer and other inputs;
- Adaptation of EPIC (Erosion Productivity Impact Calculator) to barley, wheat, vetch, and medic farming systems in northern Jordan; and
- Computer-Based Linkage System for weather/crop/livestock whole-farm models.

Whole-Farm Models. The objective behind the whole-farm modelling efforts of TSMM/EC is to develop and use methodologies for technology assessments that take into account as much as possible the interaction of soils, weather, farm resource base, farm family characteristics, farm production practices, and the particular economic setting in which technology adoption and diffusion take place, namely, the farm site. Information at this level about the impacts of new practices is necessary in order to determine the technical and financial feasibility of the farmer's adoption of a particular practice. Similarly, information on the effects at the farm level of developmental programs, policies, and associated economic consequences is important for planning and decisionmaking. TSMM/EC's farm modelling work, therefore, is designed to elucidate the farm-level changes that might be expected with technology transfer and to identify the income, food, and natural-resource farm-production practices, policies, and programs that can stimulate agricultural development.

A number of different computer-based mathematical models of representative farming systems in West Africa, North Africa, and the Near East have been completed by TSMM/EC or are currently under way, including:

- A linear programming model of a typical rainfed farming system in the semiarid region of western Mali (800-1,000 mm rainfall, a 120- to 150-day growing season);
- A discrete stochastic programming model based on a typical millet-cowpea intercrop for the Sahelian agroclimatic zone in the Maradi region of Niger (400-600 mm rainfall, a 60- to 100-day growing season);

- A Target MOTAD linear programming model to assess sorghum technology for a typical farm in southern Niger that is rainfed and receives supplemental irrigation (300-500 mm rainfall, a 60- to 100-day growing season). The model is outfitted with two expert systems to facilitate its operation in a user-friendly mode;

- A dynamic programming intertemporal model of farm-level fertilizer decisionmaking in the Sahelian agroclimatic zone; and

- A quadratic programming model of a representative wheat-barley-legume-livestock rainfed farm in northern Jordan (300 mm rainfall).

Development of Procedures for Handling Risk. One of the chief characteristics of the environment in which rainfed agriculture is carried out is variability in the timing and amount of rainfall. This variability, occurring from year to year as well as within growing seasons, creates a risky situation for farmers. When rainfall cannot be predicted with great accuracy, farmers are uncertain as to their best course of action regarding farm-production decisions. Moreover, actions taken in any one year (such as tillage practices, crop rotations, and conservation investments) will have implications for soil productivity, water storage, farm output, and farm income in the future. For these reasons, the procedures followed in technology appraisals must accommodate risk, uncertainty, and the long-term dynamics of resource use.

TSMM/EC researchers have addressed the problem of appropriate methodology. They have evaluated and compared procedures appropriate to the analysis of rainfed farming systems and have identified operational approaches for incorporating risk and uncertainty into whole-farm planning for West Africa. Target MOTAD and goal programming are the preferred approaches because they seem most flexible in terms of describing farmer behavior with respect to risk. In the future, researchers will need to separate price and yield risk and determine price risk from market conditions. In addition, intertemporal effects (such as soil erosion, crop residue management, and water conservation) must be incorporated into static, single-time-period models.

Case Studies

The analytical methodologies, data, and computer systems described thus far were put together expressly for the purpose of analyzing important agricultural issues in locations having significant food-, income-, and resource-management problems. Using these techniques and information systems, a number of case studies have been completed or are in progress. These analyses have taken the form of case studies of typical problem situations found in the rainfed farming regions of West Africa, North Africa, and the Near East.

When rainfall cannot be predicted with a high degree of accuracy, farmers are uncertain as to their best course of action regarding farm production decisions.

Mali. Six case studies were undertaken to evaluate the economic feasibility of

the various agronomic options that are available on a typical Malian farm. These analyses indicate that even in the relatively humid Sudano-Guinean zone of the Sahel where the representative farm is located, the improved soil-, water-, and crop-management technologies are cost-effective and yield large benefits in the form of increased income, production, and erosion control. Even with traditional cultivars, the combination of chemical fertilizer and tied ridges proved effective. Of major significance in these results is the increased stability in year-to-year output made possible by the water-conserving tied-ridge technology. Similarly, the erosion-control benefits of the practice further enhance the long-term sustainability of farming in the Sahelian environment.

On the other hand, short-season (90-day) cultivars made no significant difference in farm output or income. However, in situations where the seasonal distribution of rainfall is less favorable than in the scenario examined in these studies (such as later onset/earlier cessation), short-season cultivars would likely be a better choice (other things being equal) than traditional varieties. This would be particularly true in the drier northern regions of the Sahel, where the growing season is normally shorter. Also, in the drier regions where water is even more scarce, the economic returns to water conservation may be larger than those estimated.

Farms and farmers in other locations with characteristics similar to those of the representative Malian farm could experience similar economic gains, certainly in the short term. Clearly, there is a latent economic incentive for the adoption of new practices. For that reason, public policies and programs should be much more oriented to natural resources than they have been. Vigorous action is needed to remove impediments to the diffusion of better resource management at the farm level. The farm level, after all, is where most decisions concerning the use of soil and water resources are made. And it is where most improvements must take place.

Niger. A number of case studies have been developed by TSMM researchers at Purdue University. To date, the following recommendations have resulted:

- Moderate levels of phosphorus can be profitably applied by farmers who operate on sandy, low-phosphorus soils commonly encountered in Niger. This result holds when farmers are assumed to be risk averse and for a wide range of relative input/output prices. In addition, superphosphate is superior to the native phosphate sources of crushed phosphate rock and partially acidulated phosphate rock due to superphosphate's high solubility (which results in large immediate benefits) and the current price structure, which does not reflect the relative degree of solubility of the three forms. Finally, given the shortage of rainfall in recent years and the variability observed in the response to nitrogen, the application of nitrogen at current price levels would not be profitable or desirable in most years.

- Offering low-interest credit is a relatively ineffective way to encourage the adoption of agricultural technologies in Niger. A risk-bearing credit program in which the level of debt repayment is dependent on weather was found to increase the adoption of technology.

- In examining the interdependency of dryland and irrigated farming systems in the Niger River Basin, results indicate that a millet-based technology should not be introduced if the timing of its application conflicts with the transplanting date for rice in the dry season. Likewise, a rice-based technology should not be introduced if the timing of its application conflicts with the planting and first-weeding schedules of millet in the dry season.

- Hybrid sorghum yields more consistently than cowpea, millet, or cotton in the rainy season but less consistently than cotton or wheat in the dry season. Also, hybrid sorghums are more profitable than either local or improved sorghum varieties under improved cultivation practices, i.e., irrigation with fertilizer use. If the farm wheat price were at the world wheat price and input/output price variability were reduced, the model indicated that new sorghum cultivars would be adopted year-round by risk-averse farmers and on all available land in the dry season by risk-neutral farmers.

Symposia

International Conference on Dryland Farming

TSMM helped to plan and organize the International Conference on Dryland Farming, held in Amarillo/ Bushland, Texas, on August 15-19, 1988. The conference featured keynote addresses, papers, and poster presentations on such topics as soil conservation, agroclimatology, water conservation, soil fertility, residue management, socioeconomic concerns, cropping systems, environmental concerns, integrated crop/livestock systems, and pest management. More than 400 participants from 52 countries and 36 States of the United States evaluated past research and identified problems that need to be addressed in the future.

A Conference Proceedings containing the 259 papers presented was published by Texas Agricultural Experiment Station in 1990. Pre- and post-conference tours of farmers' fields and experiment stations in the U.S. Great Plains were conducted. In addition to USAID and USDA/ARS, organizations that helped to sponsor the Conference are the Texas Agricultural Experiment Station; USDA's Cooperative State Research Service (CSRS); Food and Agriculture Organization (FAO), United Nations; World Bank; Rockefeller Foundation; USDA's Soil Conservation Service (SCS); and USDA/OICD.

Management of Crop Residue

TSMM sponsored, planned, and organized a workshop entitled Crop Residue Management to Optimize Crop/Livestock Production and Resource Conservation in the Near East Region. It was held in Amman, Jordan, on January 31-February 2, 1988. The Workshop was attended by 30 participants representing National Center for Agricultural Research and Technology Transfer, Jordan National Agricultural Development Project, JUST, University of Jordan, USDA, USAID, Arab Center for Studies in the Arid Zones and Drylands, ICARDA, and WSU. Detailed plans for regionally coordinated research to establish the relative agronomic and economic importance of crop residues for soil and water conservation versus for animal feed were compiled and distributed after the workshop.

Management of Sandy Soils
The International Symposium on Managing Sandy Soils was hosted by CAZRI in Jodhpur, India, on February 6-10, 1989. TSMM cosponsored the symposium with the Indian Council of Agricultural Research (ICAR). J.F. Parr assisted the ICAR and CAZRI staffs in planning and organizing the symposium, which was attended by 150 scientists from 19 countries. TSMM scientists presented six papers.

Natural Resource Management for a Sustainable Agriculture
An International Symposium on Managing Natural Resources for a Sustainable Agriculture was held in early February 1990 in New Delhi, India. J.F. Parr assisted ICAR and the FERRO/New Delhi office of USDA/OICD in planning and organizing the symposium.

Workshop on Sustainable Land Use Systems
An International Workshop on Sustainable Land Use Systems was held in New Delhi on February 12-16, 1990. The Workshop was cosponsored by ICAR, the FERRO/New Delhi office of USDA/OICD, and the Rodale Research Center. J.F. Parr assisted in planning and organizing the workshop.

Assessment and Monitoring of Soil Quality
A Conference on the Assessment and Monitoring of Soil Quality was hosted by Rodale Institute in Kutztown, Pennsylvania, on July 11-13, 1991. J.F. Parr and R.I. Papendick helped plan and organize the conference, which included participants from the United States, Canada, U.S.S.R., United Kingdom, and FAO. Scientists discussed the importance of soil quality in sustainable agriculture issues and in environmental concerns and biogeochemical processes related to global warming. A Standing Committee was formed to define the components of a soil-quality index, to assess the state of the art in understanding soil quality, to set research priorities, and to develop a strategy for implementing an international program for assessing and monitoring soil quality.

Sabbaticals/Training

As part of establishing strong scientist-to-scientist linkages between the United States and developing countries and stimulating research and technology transfer, TSMM has sponsored sabbaticals and supported training for several researchers.

A.C.S. Rao, a soil scientist from CRIDA in Hyderabad, India, is collaborating with USDA/ARS scientists in the Land Management and Water Conservation Research Unit at WSU. As a visiting scientist, Dr. Rao is using 15N methodology in studying the effects of soil organic matter and nitrogen fertilizer rate on the fertilizer-use efficiency of spring wheat at various growth stages. Improved understanding of the use efficiency of applied nitrogen should lead to better recommendations for application rates of fertilizers.

S.S. Prihar, a soil scientist from Punjab Agricultural University, Ludhiana, India, was a visiting scientist for 1 year (April 1988 to March 1989) at the USDA/ARS Conservation and Production Laboratory in Bushland, Texas. He conducted cooperative research with the ARS scientists to develop management practices for increased water conservation and improved water-use efficiency by dryland crops.

D. Ngambeki, an agricultural economist with the IITA-SAFGRAD Farming System Project in Cameroon is spending a 1-year sabbatical at Purdue University with TSMM/EC support. He is working with R. Deuson and J. Lowenberg-DeBoer. Their work is focused on the stability, sustainability, and profitability of improved dryland farming in northern Cameroon using data from 6-7 years of trials, field plots, and participating farmers.

TSMM also partially funded the laboratory and field research of S.K. Khattari and R.I.P. Fardos, soil scientists of the Department of Soils and Irrigation, University of Jordan, Amman, Jordan. Both scientists collaborated with R.I. Papendick and his staff and the USDA/ARS Land Management and Water Conservation Research Unit at Pullman, Washington.

Cooperative Research

TROPSOILS
TSMM participated in a cooperative project in Niamey, Niger, through TROPSOILS, a USAID Collaborative Research Support Program administered through Texas A&M University. The project is titled "Transfer of Soil and Water Management Technologies." First-year results indicate that the proper management of crop residues can effectively increase soil-water storage in Sahelian soils. Future research will determine whether the additional soil water will significantly reduce the risk associated with dryland farming and stabilize yields.

Jordan University of Science and Technology
TSMM developed a research proposal with A.A. Jaradat, an agronomist at JUST in Irbid, Jordan. The study is designed to determine the agronomic and economic value of crop residues for water conservation versus for feed for small ruminant animals. The research has begun, and TSMM has provided seed money via a cooperative agreement between WSU and JUST.

Prediction of Wind Erosion and Evaluation of Feasible Control Techniques
D.W. Fryrear, USDA/ARS, Big Spring, Texas, is cooperating with soil scientists at the Rabat Institute in Morocco. Objectives of the project include (1) measurement of wind erosion, characterization of windblown sediments, and monitoring of the environmental factors affecting wind erosion in Morocco; (2) development of an erosion-prediction system that is specific to southern Morocco; (3) evaluation and comparison of the relative effectiveness of the existing wind-erosion-control systems; and (4) production of a handbook for the local technicians on the upgraded design criteria for the selected wind-erosion-control systems.

Measurement and Prediction of Soil Erosion in the Caribbean
R.A. Young, USDA/ARS, Morris, Minnesota, is collaborating with scientists in the Dominican Republic and Haiti in an effort to characterize and predict soil erosion. Runoff plots have been established to study the effects of various soil-management practices on soil loss and runoff. Data will be used to adapt two models, AGNPS (Agricultural Non-Point-Source Pollution) and RUSLE (Revised Universal Soil Loss Equation), for use in predicting erosion and evaluating management techniques.

Network for Sustainable Agriculture

The use of conservation tillage methods (such as minimum tillage or no-till), stubble mulching, cover crops, legume-based crop rotations, and application of composts, animal manures, and green manures can increase soil-water retention and fertility, improve soil tilth, and reduce soil erosion by wind and water. When these practices are used individually and in combination with one another, the need for high-cost inputs (mineral fertilizers, pesticides, herbicides, etc.) can be reduced while productivity is maintained or increased. In developing countries where external inputs are generally unavailable to farmers due to inadequate supplies and high costs, conservation technologies are attractive alternatives.

Under the leadership of J.F. Parr and S.B. Hornick, TSMM has assumed a pivotal role in disseminating information on sustainable agriculture to researchers in developing countries.

Study Tour

TSMM organized and sponsored a study tour of dryland/rainfed farming systems in the U.S. Great Plains for 30 program managers and administrators from the World Bank, USDA/OICD, USDA/CSRS, USDA/SCS, USDA's Extension Service, and the Agriculture Division of USAID's Bureau for Science and Technology on July 10-16, 1988. The tour emphasized low-input, sustainable-agriculture techniques and systems that have potential for adaptation to developing countries. The itinerary included visits to commercial farms, agricultural experiment stations, and major land-grant universities in Iowa, Kansas, and Nebraska. Participants observed low-input and sustainable-agriculture practices and met with scientists and farmers to discuss underlying economics. Conservation tillage, crop-residue management, recycling of animal manures, and ridge-till planting helped to alleviate the impact of the 1988 drought on crop growth and yield.

Asia-Pacific Natural Agriculture Network

The Asia-Pacific Natural Agriculture Network (APNAN) was founded during the First International Conference on Kyusei Nature Farming, held October 17-21, 1989, in Khon Kaen and Bangkok, Thailand. The purpose of APNAN is to foster low-input/sustainable farming systems in countries of the Asia/Pacific region. A strong consensus was that this could be done by establishing an international, nongovernmental, nonpolitical association of scientists to promote research that would lead to the development of agricultural practices and technologies with the following objectives:

(1) To avoid or to largely exclude the use of synthetic agricultural chemicals, especially fertilizers and pesticides;

(2) To enhance the quality of the environment and the protection of the natural resource base;

(3) To improve the productivity and profitability of small farmers and the long-term sustainability of their farming systems;

(4) To optimize the use of on-farm resources and minimize the dependence of farmers on off-farm resources and purchased inputs; and

(5) To enhance the safety and nutritional quality of food.

Conservation technologies can reduce the need for high-cost inputs such as mineral fertilizers, pesticides, and herbicides.

The first meeting of the Steering Committee of APNAN was held April 17-18, 1990, in Atami, Japan. Facilities for this meeting were provided by the International Nature Farming Research Center. Representatives from Thailand, Pakistan, Philippines, Indonesia, Bangladesh, Taiwan, Korea, India, Sri Lanka, Myanmar (Burma), Malaysia, and Japan attended. J.F. Parr and S.B. Hornick, USDA/ARS, serve as the U.S. technical advisers to APNAN.

A high priority for APNAN members is to conduct similar field experiments to determine the proper use of organic amendments to optimize soil productivity and sustainability. Results from this research initiative were reported at the APNAN Steering Committee meeting in January 1991 in Kuala Lumpur, Malaysia.

Global Change

TSMM has cooperated with the Office of the Secretary, USDA, and the Response Strategies Working Group (RSWG) of the Intergovernmental Panel on Climate Change (IPCC) on a number of efforts. C.E. Whitman has identified developing-country scientists and policymakers from Africa, Asia, the Near East, and South America for participation in IPCC global change workshops and authored the Food Security Summary for the Interim Report of RSWG to IPCC.

Proceedings/Publications

TSMM has been very active in supporting, publishing, and distributing information on rainfed and dryland agricultural research and management. The following publications contribute to a better understanding of the vital components of dryland farming systems and the proper integration of those components to ensure economic and environmental sustainability. The publications also identify research needs, research priorities, and strategies to minimize the risks of dryland agriculture worldwide.

- "Proceedings of the Workshop on Soil, Water and Crop Management Systems for Rainfed Agriculture in Northeast Thailand" was published by USDA in 1988. The workshop was held in Khon Kaen, Thailand, in early 1985. Approximately 500 copies have been distributed to workshop participants and to scientists and institutions that are interested in rainfed agriculture in the semiarid Tropics.

- "An Assessment of Research Needs and Priorities for Rainfed Agriculture in Jordan," edited by A.A. Jaradat of JUST, contains chapters on soil resources, agroclimate, traditional agronomic practices, governmental policy, and use of models in agricultural research. This database will contribute to a better understanding of dryland/rainfed agricultural systems and improved decisionmaking in Jordan and the Near East region.

- "Response Farming in Rainfed Agriculture," by J.I. Stewart of World Hunger

Leaving residue from a previous crop is a good way to put back at least as much fertility as you've taken out. Some say that anything else is not farming: it is mining the soil of water, minerals, and organic matter.

Alleviation Through Response Farming, is a report on a new method of assisting farmers with crop-management decisions in areas with limited and variable rainfall. Response farming models have been developed for use in North America, Africa, the Near East, and Asia.

- "Soil Erosion Research Methods," edited by R. Lal and published by the International Soil Science Society and the Soil and Water Conservation Society, was partially funded by TSMM. Copies have been distributed to international organizations, national research and extension agencies, and scientists in countries of the arid and semiarid regions.

- "Proceedings of the Workshop on Soil, Water, and Crop/Livestock Management Systems for Rainfed Agriculture in the Near East Region" was published by USDA. The workshop was held in Amman, Jordan, in early 1986 and was cosponsored by TSMM and ICARDA. Copies have been distributed to workshop participants, libraries, International Agricultural Research Centers (IARC's), national research and extension agencies, and research scientists that are interested in soil- and water-management systems for dryland/rainfed agriculture.

- "Proceedings of a Workshop on Crop Residue Management to Optimize Crop/Livestock Production and Resource Conservation in the Near East Region" reviews strategies for improved crop/livestock production systems through the effective use of crop residues for enhanced soil and water conservation. The workshop was held in Amman, Jordan, on January 31-February 2, 1988, and was cosponsored by TSMM and ICARDA.

The proper use of organic amendments can optimize long-term soil productivity and sustainability.

- "Erosion, Productivity, and Sustainable Agriculture" is the report of a workshop held in 1988 and cosponsored by TSMM and the International Center for Arid and Semiarid Land Studies. The workshop was convened to assess the impact of soil erosion on agricultural productivity and sustainability and to identify research needs and priorities.

- "Land Erodibility Assessment Methodology," by L.A. Manrique, describes how the potential erosion risk of lands can be assessed by the use of information from soil surveys based on USDA's "Soil Taxonomy."

- "Proceedings of the Workshop on Soil, Crop, and Water Management Systems for Rainfed Agriculture in the Sudano-Sahelian Zone" was published by ICRISAT in cooperation with TSMM. The workshop was held in Niamey, Niger, in 1987.

- "Dryland Agriculture: Strategies for Sustainability" is a special issue of "Advances in Soil Science" (vol. 13) coedited by R.P. Singh (Director, CRIDA, Hyderabad, India), J.F. Parr, and B.A. Stewart. This monograph contains reviews of recent developments in dryland farming technologies and methodologies.

- The Proceedings of the International Conference on Dryland Farming, entitled "Challenges in Dryland Agriculture: A Global Perspective," was edited by P.W. Unger and others and was published by the Texas Agricultural Experiment Station. It is a compendium of technical papers on dryland agriculture presented at the conference held at Amarillo/Bushland, Texas, on August 15-19, 1988.

- "Proceedings of the First International Conference on Kyusei Nature Farming" provides information on a new area of research. The use of beneficial microorganisms as inoculants to increase the biodiversity of agricultural soils and thereby enhance the growth and yield of crops is examined. The workshop was held in Khon Kaen, Thailand, in 1989 and was cosponsored by TSMM, Sekai Kyusei Kyo (Atami, Japan), and International Nature Farming Research Center (Atami, Japan).

New Ventures

ARS researcher Phil Dukes has developed pest-resistant sweet potatoes that can be grown with low pesticide inputs. These new varieties are being tested in South Africa for possible use by subsistence farmers.

Uganda

The Uganda Manpower for Agricultural Development Project (MFAD), a USAID-funded bilateral project with Ohio State University as the lead U.S. institution, is implementing a comprehensive effort to improve crop production and organic-matter management in Uganda. The host-country agencies involved in this cooperative project are the Ministry of Agriculture and Makerere University. At the request of MFAD, TSMM will assist in the implementation of a project on Soil and Water Management, providing technical support for research and training on soil and water management.

To date, TSMM has agreed to support the development of a database on soil-water research conducted in-country that is relevant to practices that would halt further degradation of the natural resource base and is particularly relevant to current farming systems. J. Zake, Chairman, Department of Soil Science, Makerere University, has been identified as the cooperating in-country scientist. Subsequently a workshop will be organized to assess the database findings and establish research needs, research priorities, and an action program for halting further land degradation.

Republic of Ciskei, South Africa

At the request of the Agronomy Department, University of Fort Hare, Republic of Ciskei, J.F. Parr visited this black university on February 16-18, 1990, to consult with staff members on aspects of dryland/rainfed agricultural research. Dr. Parr has now developed an exploratory cooperative research project with J.N. Marais, Professor of Agronomy, to evaluate the performance of five new varieties of sweet potatoes that were developed by ARS researchers at the U.S. Vegetable Laboratory in Charleston, South Carolina. The ARS researchers have found that these new varieties of sweet potatoes can be grown with a significantly lower input of pesticides than the inputs used with currently available varieties. This would provide a major impetus for the production of sweet potatoes by subsistence farmers in South Africa where this crop could become a major food source. Currently, sweet potatoes are expensive to produce because heavy amounts of pesticides are required to control diseases and insects.

Dr. Parr has arranged for samples of the five U.S. sweet potato varieties to be shipped to the South African Directorate of Plant and Liquor Control at Pretoria, where the potatoes will be grown under quarantine before they are released to researchers at the University of Fort Hare. This involvement is particularly noteworthy because Dr. Parr has responsibilities under the 1890 HBCU (historically black colleges and universities)-ARS Research Programs and cooperates with Southern University in Baton Rouge, Louisiana. Dr. Parr will continue to assess the performance of these new sweet potato varieties in the black homeland Republic of Ciskei and will render assistance to staff members at the University of Fort Hare.

Botswana

The Southern African Centre for Cooperation in Agricultural Research (SACCAR) with headquarters in Gabarone, Botswana, is an organization of the Southern African Development Coordination Conference (SADCC). The function of SACCAR is to coordinate agricultural research in the SADCC Region, which includes nine member countries (Angola, Botswana, Lesotho, Malawi, Mozambique, Swaziland, Tanzania, Zambia, and Zimbabwe). SACCAR has requested that our USDA/USAID PASA Project (TSMM) take the lead in helping to organize and conduct a workshop on Improving and Sustaining the Productivity of Dryland Farming Systems in the SADCC Region. In doing this, we would draw heavily on N. Persaud, a soil scientist with the International Sorghum Millet Collaborative Research Support Program/Kansas State University in Botswana.

Many of the SADCC countries are unable to meet their population demands for food grains because of inadequate soil- and water-management practices, excessive soil erosion and nutrient runoff losses, and erratic and insufficient rainfall. These countries would benefit considerably from the proposed workshop and the research and extension networking activities that would result. Other agencies that have expressed an interest in supporting this effort are FAO, Overseas Development Agency, IBSNAT, ICRISAT, and ICARDA.

Conclusions and Recommendations

The Environmental Factor

In the Near East, Africa, and Asia, the principal problem of agricultural productivity is insufficient rainfall. Other constraints are

Erratic rainfall

Excessive runoff

Severe erosion

Poor soil tilth

Low soil fertility

The Human Factor

Demonstrations and on-farm trials can show farmers actual promising technologies that can overcome

Shortage of cash

Lack of technology

Poor communication

Financial risk

The constraints to agricultural productivity in arid and semiarid regions are common among the countries in the Near East, Africa, and Asia. The constraints are erratic rainfall, large water losses, erosion, and poor soil tilth and fertility. The principal problem is insufficient water.

Currently available technology can be used to alleviate these constraints. In some dryland/rainfed systems, existing technology may need to be modified or new technologies developed. The following general recommendations have emerged:

(1) More-uniform and more-comprehensive classification of soils and agroclimate is needed, combined with land-use mapping, in order to develop crop recommendations for various agroclimatic zones.

(2) The application of soil- and water-conserving practices, such as soil amendments (crop residues, manure, etc.), tillage, water harvesting, and weed control, is necessary to improve water infiltration and soil fertility, reduce water loss, and control erosion. An understanding of the interactions of fertility and soil moisture is key to improving productivity.

(3) In order to increase crop yields but reduce the cost of fertilizer to the farmer, internal inputs such as onfarm organic materials should be exploited first; they can be supplemented when necessary with purchased inputs. Times, rates, methods, and frequencies of application must be optimized with respect to cost, crop yield, and water- and nitrogen-use efficiency for combined nitrogen sources, i.e., mineral and organic nitrogen. Applications of phosphorus may be necessary to raise the productivity of the resource base.

(4) Farmers are reticent about new technologies for reasons related to financial risk, technical know-how, shortage of cash, and other socioeconomic considerations. Efforts should be increased to conduct adaptable onfarm trials and demonstrations of promising technologies.

TSMM has stimulated communication and cooperation among scientists who are working on soil- and water-management issues. TSMM has also enhanced the awareness of U.S. expertise in dryland technologies among developing-country scientists and among project managers and staff of such international development agencies as the World Bank, FAO, Winrock International, International Development Research Center, and the IARC's. Further cooperation and collaboration should contribute to more effective dryland development.

Furrow dikes or tied ridges trap rainfall, allowing moisture to gradually seep into the soil. (facing page)

Further cooperation among international development agencies should contribute to more effective dryland farming.

Appendix A. Cost-Sharing Activities

Collaborations with other agencies, research centers, and universities are cost-sharing activities that have allowed TSMM to maintain its level of productivity in spite of decreased funding levels.

Asia

In Asia, the India PL-480 Dryland Project exemplifies such a cooperative effort. TSMM provided technical assistance via the U.S. Dryland Farming Team to the five emerging projects. TSMM contributions to these projects total approximately $10,000. The other major collaborators, FERRO and ICAR, contributed approximately $56,000 to these cost-sharing activities.

TSMM also provided $55,000 for the support of Dr. Rao (CRIDA) and Dr. Prihar (Punjab Agriculture University) during their U.S. training. ICAR supplied $15,000 in cost-sharing funds to their research.

In another cooperative effort, TSMM supported the February 1990 symposium on Natural Resource Management for a Sustainable Agriculture held in New Delhi, India, followed by the Rodale working group meetings on Land Management Systems for Sustainable Agriculture. TSMM supported several scientists' participation and assisted in planning and organizing these events, contributing about $22,000. Cosponsors were ICAR and FERRO, whose contributions totaled $20,000 (see fig. 1).

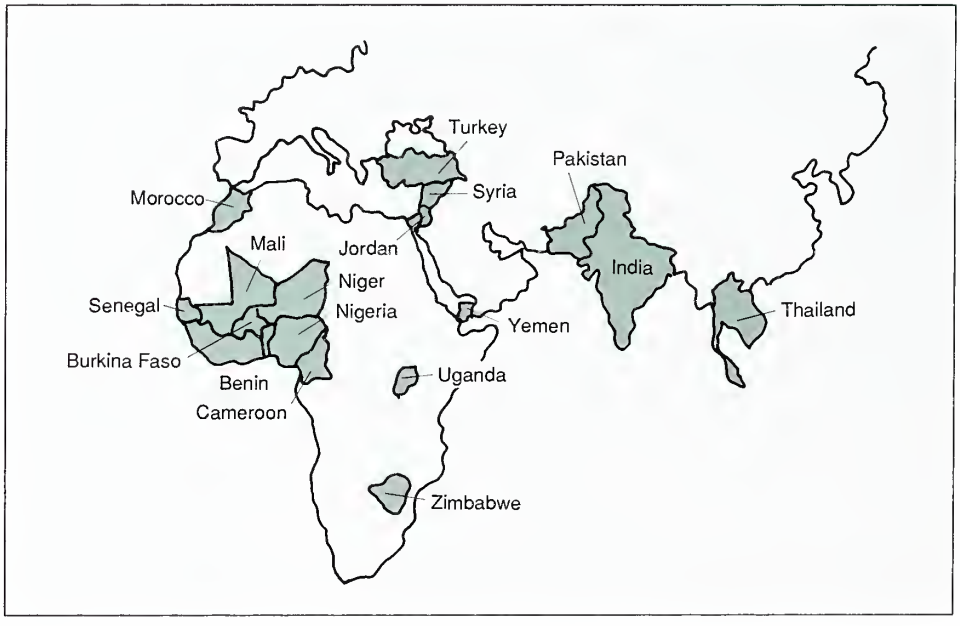
Near East

In the Near East, TSMM has been involved with several research activities in Jordan in cooperation with JUST, University of Jordan, ICARDA, USDA/ARS, and ARS/WSU. For the collaborative research on phosphorus transformations in dryland systems, the contributions of the University of Jordan are valued at $30,000 and those of ARS/WSU at $15,000. The Ribbon Project on crop residues received cost-sharing from JUST of $10,000. TSMM cooperative agreements and other support for these projects in Jordan were approximately $79,000.

TSMM also participated in a workshop in Turkey on Soil Crop Management Potential for Improved Water Use Efficiency in Rainfed Areas. TSMM input for this workshop was $8,000. ICARDA sponsored this workshop with funding of $20,000 (fig. 1).

Africa

TSMM/EC has cooperated with several universities and research centers on activities in Africa. For example, TSMM provided services and agreements estimated at $164,000 for such activities. Collaborators' inputs were approximately $21,000 (fig. 1).



TSMM's efforts are directed toward extremely poor countries in the Near East, sub-Saharan Africa, and South-Southeast Asia where there is a critical need to increase the productivity and stability of dryland farming systems.

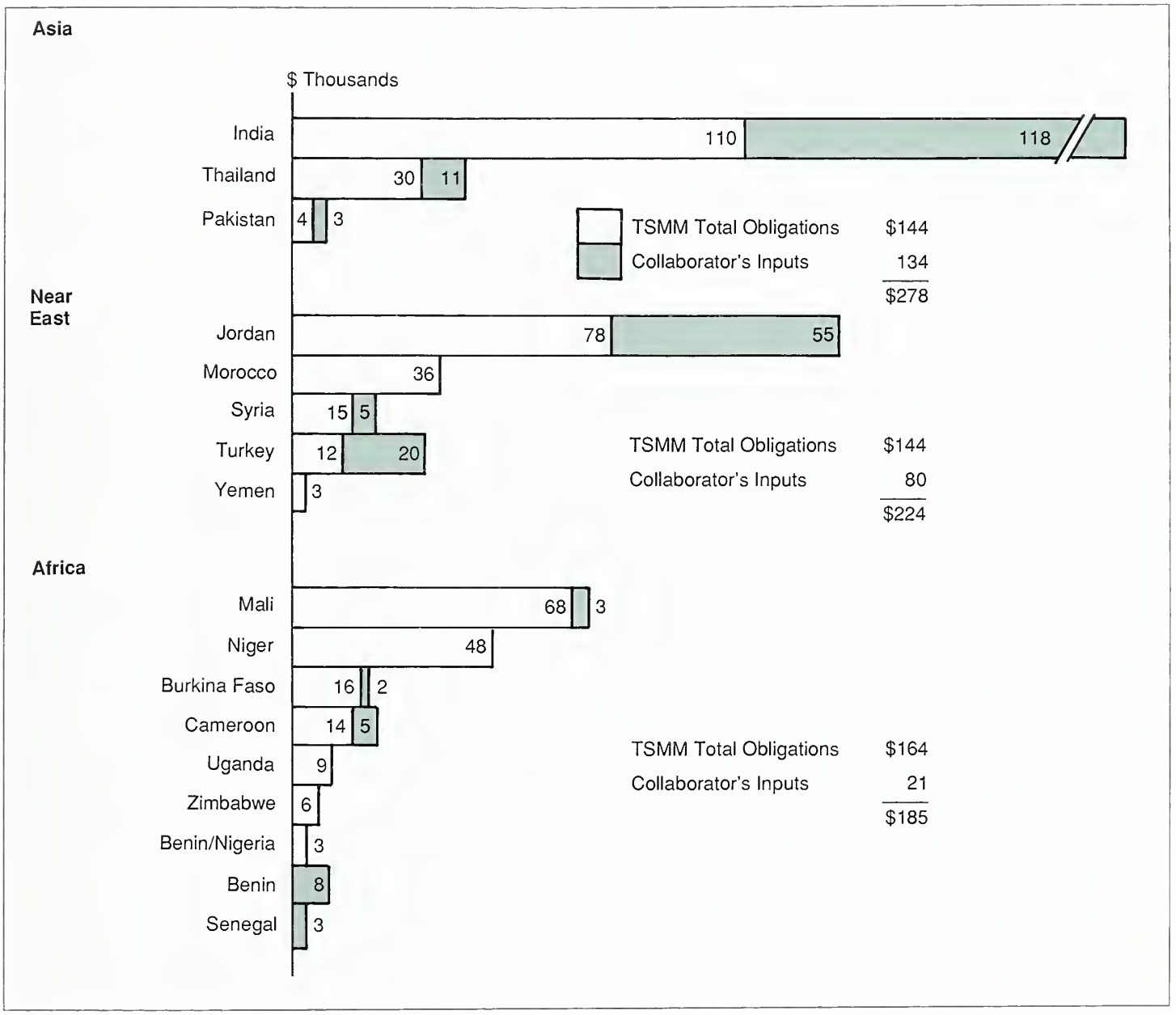


Figure 1. Funding of TSMM projects in three geographical regions.

Appendix B. Publications, Reports, and Papers

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